Physiological and molecular changes in plants at low temperature

Cold or chilling stress

Fisiologia Molecular do stress

Anabela Bernardes da Silva

Summary

Cold or chilling stress in plants :

- Short chill in light and dark on photosynthesis, primary effects
- C4 photosynthesis, a short review of the three main C4 sub-types
- Short dark-chilling effects on C4 photosynthesis

Cold and chilling stress in plants

1.3. Short chill in light and dark on photosynthesis: primary effects

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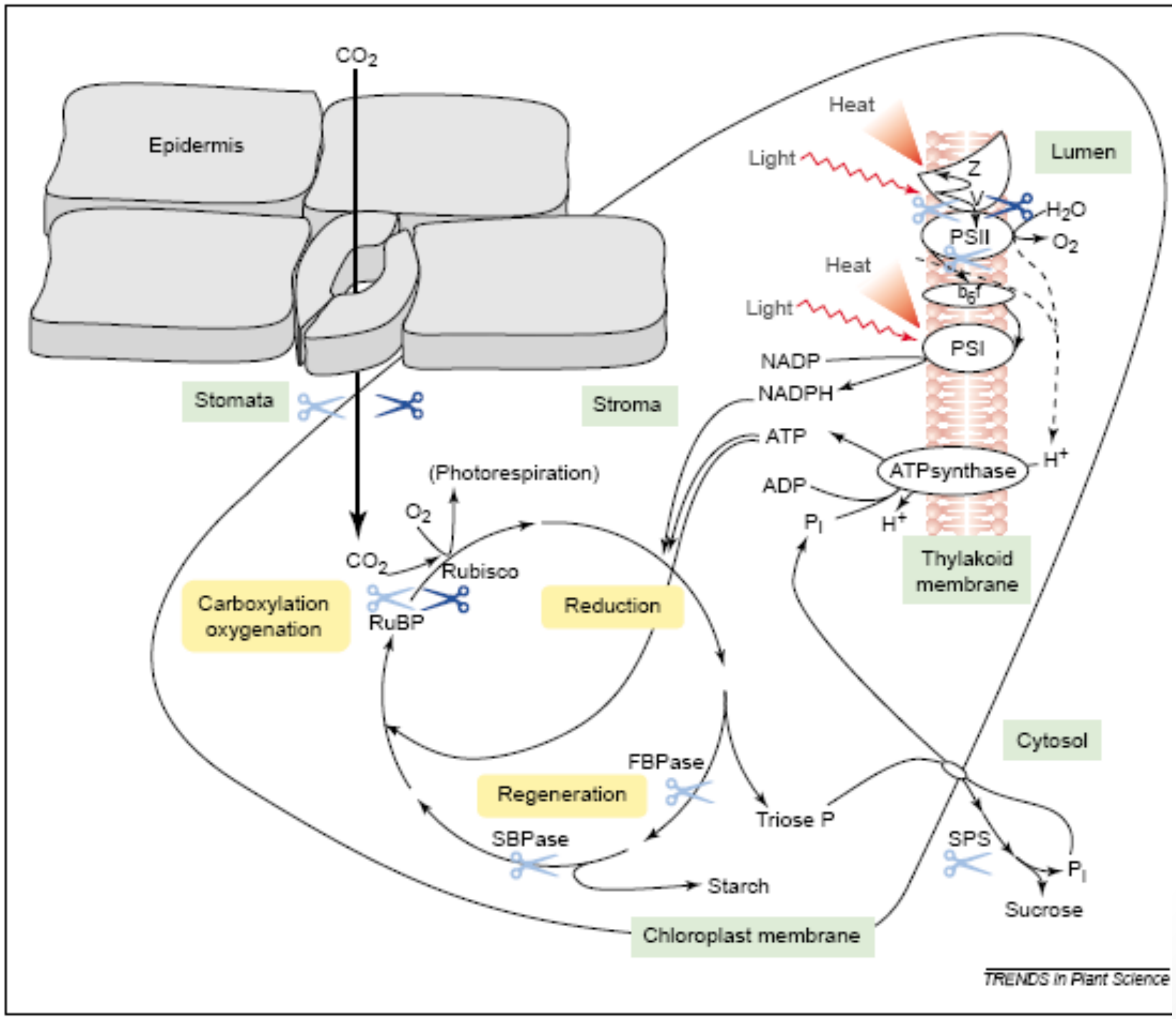
Fig. 1. Primary effects of a short chill in the light and the dark on photosynthesis in thermophilic plants. Chilling effects are apparent within the processes of photophosphorylation in the thylakoid membrane, the carbon reduction cycle in the stroma, carbohydrate use in the cytosol and the CO_2 supply to the chloroplast through the stomata. Abbreviations: ATPsynthase, chloroplast ATP synthase; b_6f, cytochrome b_6f complex; FBPase, chloroplast fructose 1,6-bisphosphatase; P_i, inorganic phosphate; PSI, photosystem-I complex; PSII, photosystem-II complex; RuBP, ribulose 1,5-bisphosphate; SBPase, sedoheptulose 1,7-bisphosphatase; V, violaxanthin; Z, zeaxanthin and antheraxanthin; light-blue scissors represent the primary impact of a light chill; dark-blue scissors represent the primary impact of a dark chill.



Cold and chilling stress in C4 photosynthesis

1.3. Dark-chilling effects on carbohydrates metabolism

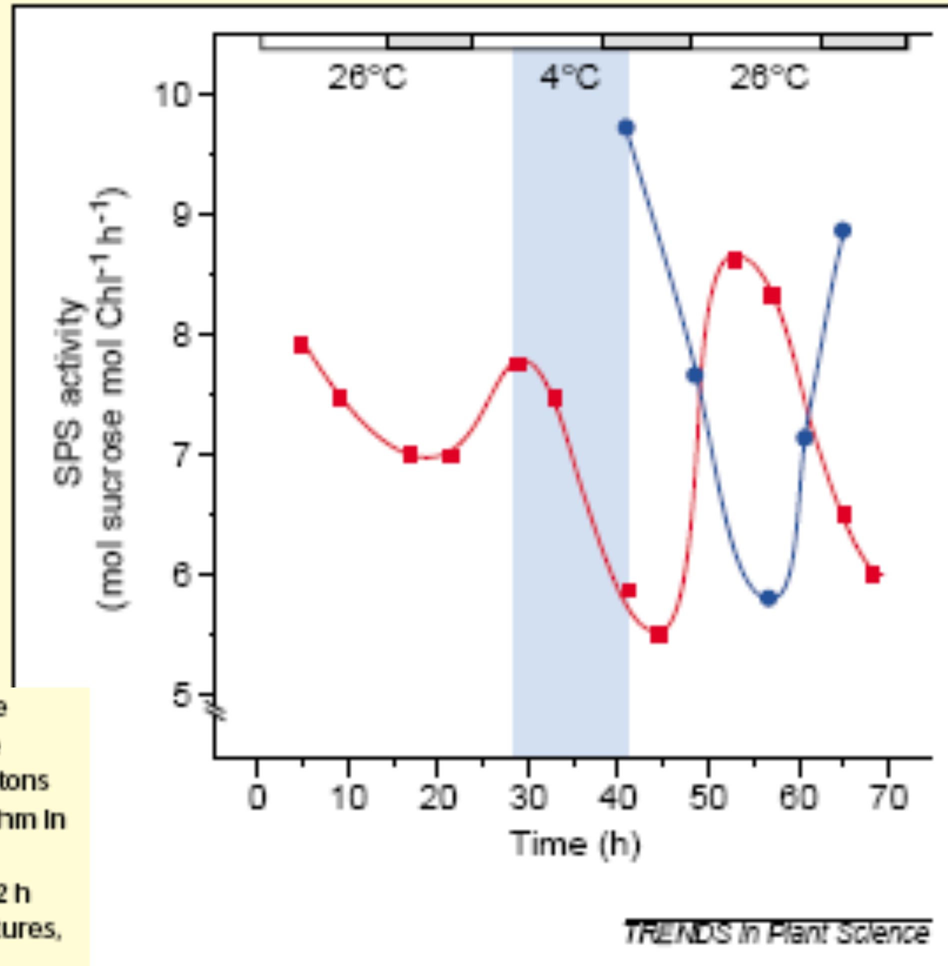


Fig. I. Chilling delays the circadian rhythm in sucrose phosphate synthase (SPS) activity. Control (red square) tomato plants were maintained under constant conditions of low-light [50 µmol photons $m^{-2} s^{-1}$] at 26°C for 3 days, and exhibit a robust endogenous rhythm in SPS activity. This rhythm was held in abeyance during a 4°C (blue circle) treatment under the same low-light conditions for 12 h (pale-blue shaded area). When returned to permissive temperatures, the circadian rhythm resumed but with a ~12 h phase shift. The light and dark bars at the top of the figure reflect the subjective day and night during this constant illumination.
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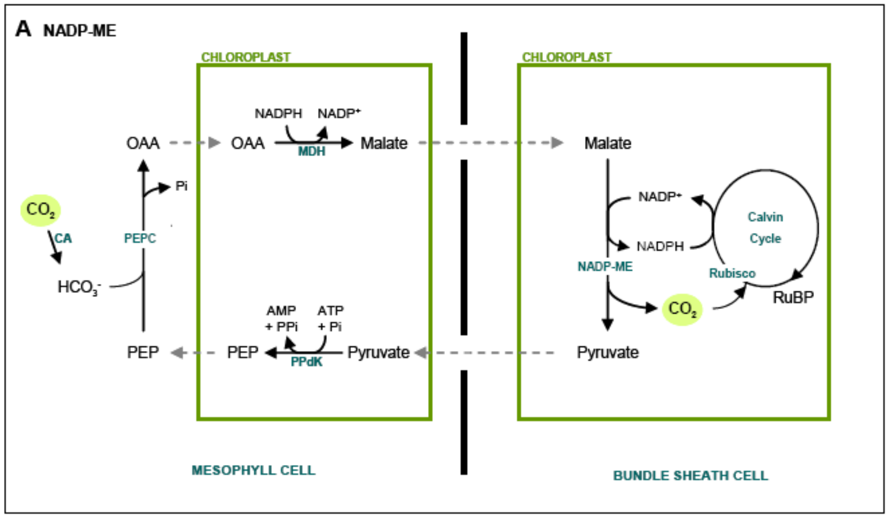
C4 Photosynthesis, a short review: three main C4 sub-types

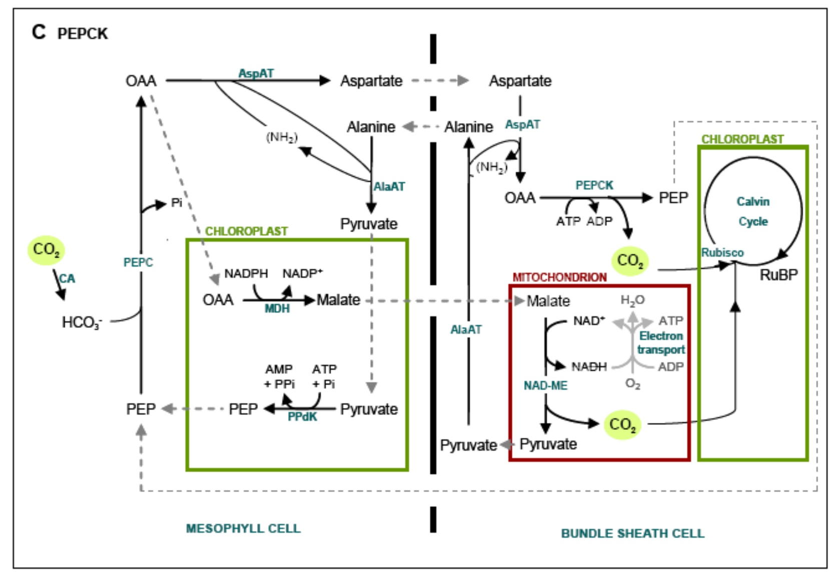


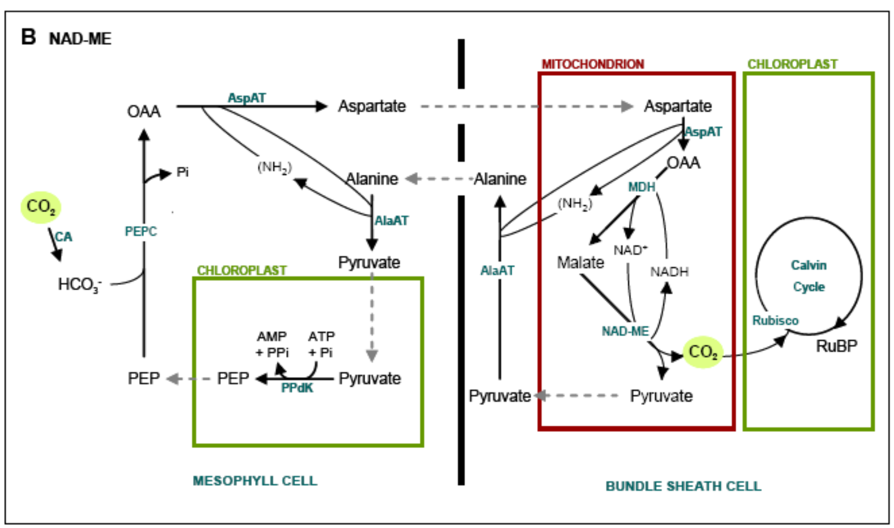
Examples:

Zea mays, Paspalum dilatatum, C4 NADP-ME

Cynodon dactylon, C4 NAD-ME plant

Zoysia japonica, C4 PEPCK plant





Kanai & Edwards, 1999, adapted by E Carmo-Silva, 2008, PhD thesis, UL

Cold and chilling stress in plants

Short chill in light and dark on photosynthesis, primary effects

And in C4 plants, what will change?

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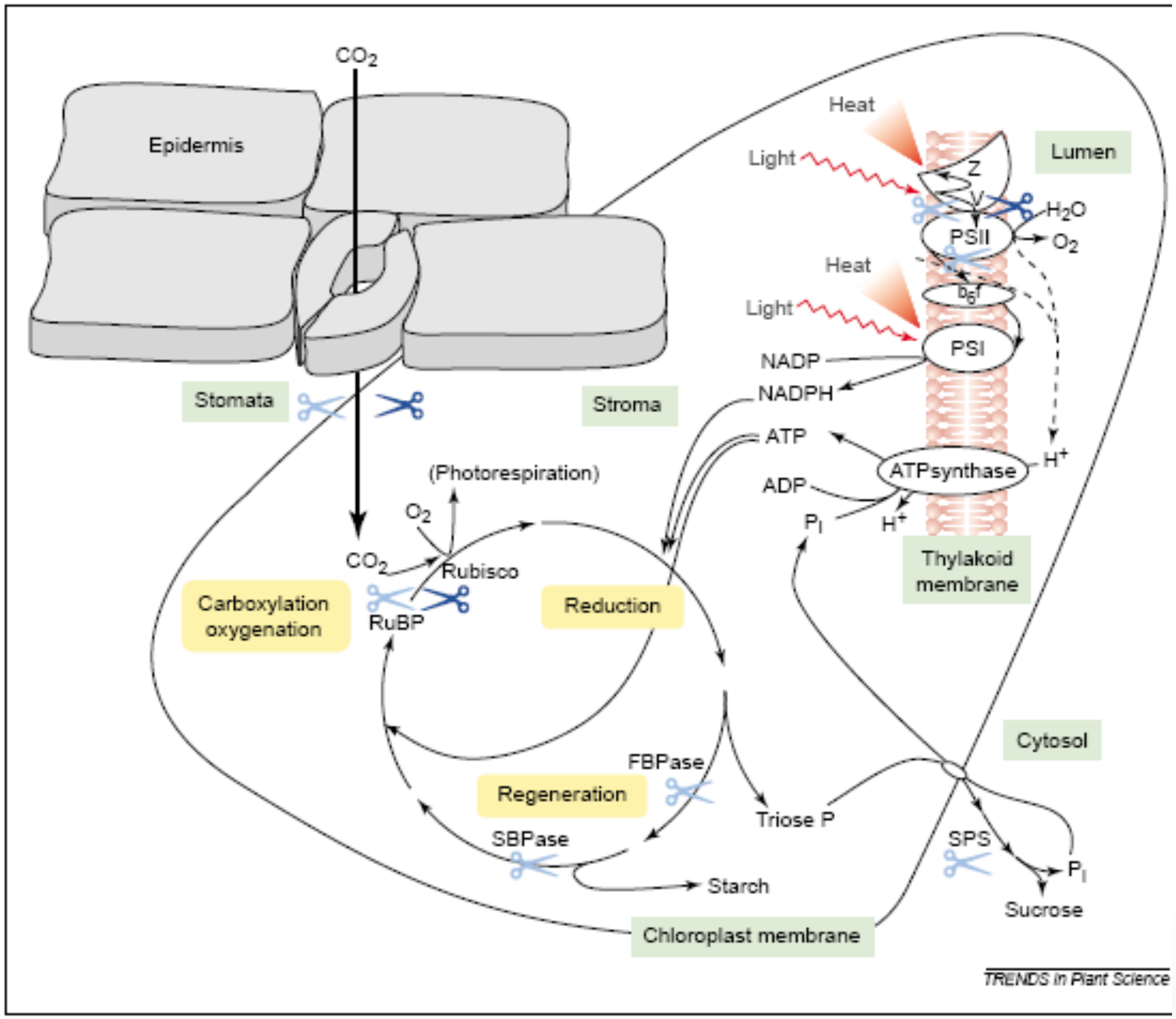
Fig. 1. Primary effects of a short chill in the light and the dark on photosynthesis in thermophilic plants. Chilling effects are apparent within the processes of photophosphorylation in the thylakoid membrane, the carbon reduction cycle in the stroma, carbohydrate use in the cytosol and the CO_2 supply to the chloroplast through the stomata. Abbreviations: ATPsynthase, chloroplast ATP synthase; b_6f, cytochrome b_6f complex; FBPase, chloroplast fructose 1,6-bisphosphatase; P_i, inorganic phosphate; PSI, photosystem-I complex; PSII, photosystem-II complex; RuBP, ribulose 1,5-bisphosphate; SBPase, sedoheptulose 1,7-bisphosphatase; V, violaxanthin; Z, zeaxanthin and antheraxanthin; light-blue scissors represent the primary impact of a light chill; dark-blue scissors represent the primary impact of a dark chill.



Cold and chilling stress in plants
1. Dark-chilling effects on C4 photosynthesis

Table 3.3. Maximal rate of photosynthesis (*Amax*), apparent quantum yield (ϕ), curvature degree (θ) and mitochondrial respiration (*Rd*) predicted from the photosynthetic light-response curve for control and one night-chilled plants of *Paspalum dilatatum*, *Cynodon dactylon* and *Zoysia japonica* (See Fig. 3.1.). Data are mean ± SD of ten plants of each species *per* treatment. The statistical analysis was performed separately for each species. The different letters represent statistical differences at P<0.05.

	Amax ($\mu mol\ m^{-2}\ s^{-1}$)	ϕ ($*10^2\ \mu mol\ \mu mol^{-1}$)	θ (relative units)	Rd ($\mu mol\ m^{-2}\ s^{-1}$)
P. dilatatum				
Control	36 ± 3.1 a	8.7 ± 1.34 a	0.78 ± 0.110 a	7.8 ± 1.49 a
1 Night Chilling	31 ± 4.8 b	8.5 ± 1.67 a	0.81 ± 0.086 a	7.4 ± 1.87 a
C. dactylon				
Control	55 ± 6.5 a'	8.8 ± 1.17 a'	0.76 ± 0.103 a'	8.2 ± 1.15 a'
1 Night Chilling	46 ± 5.0 b'	8.7 ± 1.27 a'	0.75 ± 0.106 a'	7.8 ± 1.23 a'
Z. japonica				
Control	27 ± 3.8 a''	8.6 ± 1.91 a''	0.79 ± 0.130 a''	4.5 ± 0.97 a''
1 Night Chilling	17 ± 4.5 b''	6.4 ± 1.76 a''	0.91 ± 0.062 a''	4.5 ± 1.12 a''

Soares, ASC (2008) PhD Thesis, FCUL, Portugal

Cold and chilling stress in plants
1.1. Dark-chilling effects on C4 photosynthesis: stomata responses

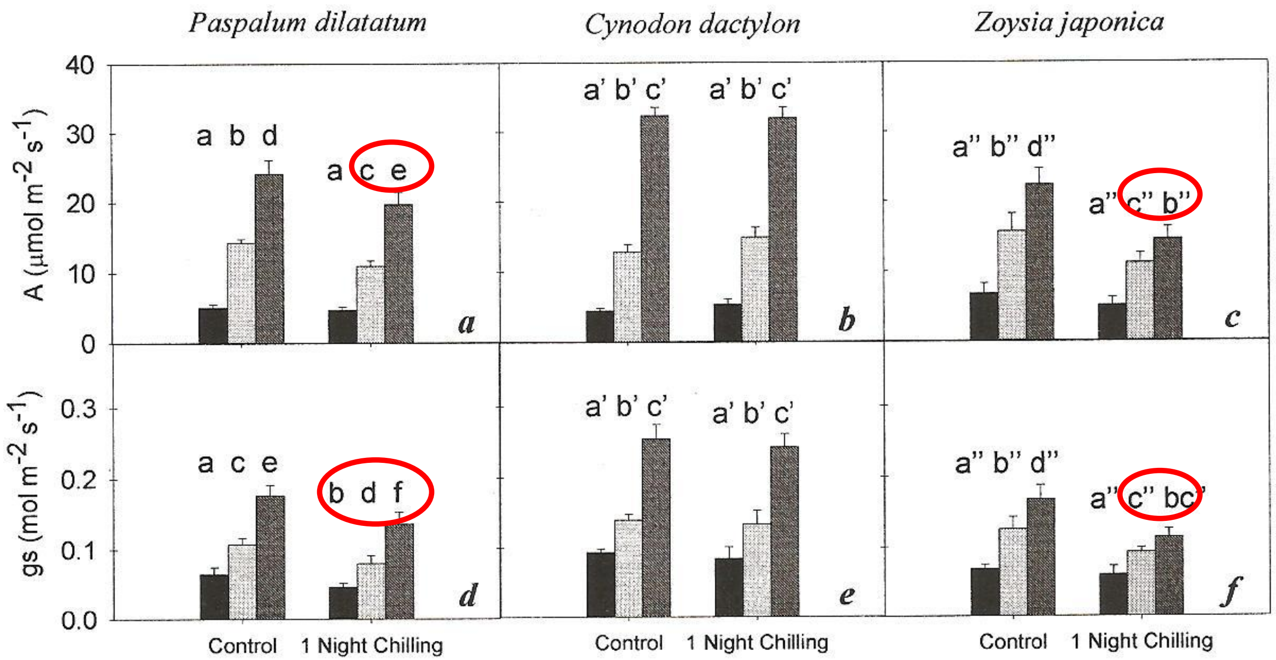


Figure 3.3. Net CO_2 assimilation rate (*A*; ***a***, ***b***, ***c***) and stomatal conductance to water vapour (*gs*; ***d***, ***e***, ***f***) at three light intensities for control and one night-chilled plants of *Paspalum dilatatum* (***a***, ***d***), *Cynodon dactylon* (***b***, ***e***) and *Zoysia japonica* (***c***, ***f***). Measurements were performed simultaneously with chlorophyll *a* fluorescence assays (See Fig. 3.4. and Fig. 3.5.) under a CO_2 concentration of 350 µL L^{-1}, at 25ºC and at a PPFD of 200 µmol m^{-2} s^{-1} (black bars), 530 µmol m^{-2} s^{-1} (grey bars) and 1300 µmol m^{-2} s^{-1} (dark grey bars). Data are mean ± SD of ten plants of each species *per* treatment. The statistical analysis was performed separately for each species. The different letters represent statistical differences at $P<0.05$.

Soares, ASC (2008) PhD Thesis, FCUL, Portugal

Cold and chilling stress in plants
1.2. Dark-chilling effects on C4 photosynthesis: electron transport

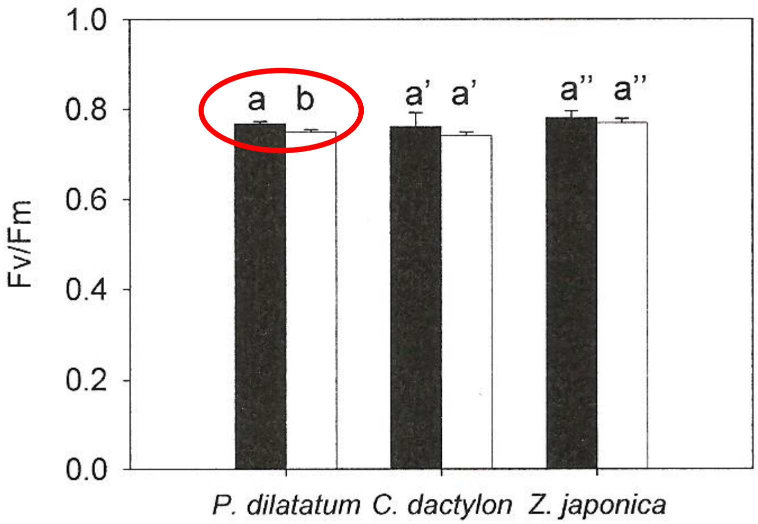


Figure 3.4. Maximum photochemical efficiency of PSII reaction centres of dark adapted leaves (*Fv/Fm*) of *Paspalum dilatatum*, *Cynodon dactylon* and *Zoysia japonica* control (black bars) and one night-chilled (white bars) plants. Measurements were performed simultaneously with gas-exchange measurements (See Fig. 3.3.). Data are mean ± SD of ten plants of each species *per* treatment. The statistical analysis was performed separately for each species. The different letters represent statistical differences at $P<0.05$.

Soares, ASC (2008) PhD Thesis, FCUL, Portugal

Cold and chilling stress in C4 photosynthesis
1.3 Dark-chilling effects on carbohydrates metabolism

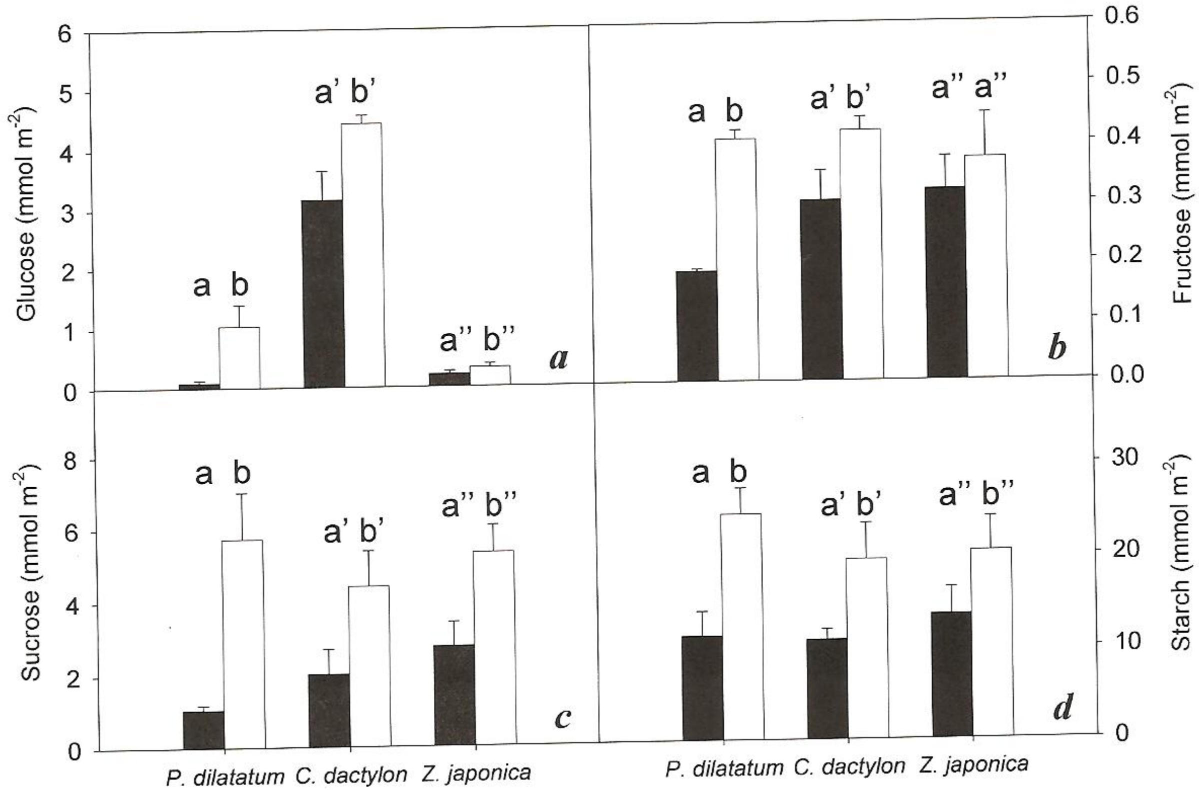


Figure 4.1. Leaf carbohydrates content of control (black bars) and one night-chilled (white bars) plants of *Paspalum dilatatum*, *Cynodon dactylon* and *Zoysia japonica*. Data for soluble (glucose, ***a***; fructose, ***b***; sucrose, ***c***) and insoluble (starch, ***d***) carbohydrates correspond to the mean ± SD of 14 plants of each species *per* treatment. The statistical analysis was performed separately for each species. The different letters represent statistical differences at P<0.05.

Soares, ASC (2008) PhD Thesis, FCUL, Portugal

Cold and chilling stress in C4 photosynthesis

1.3. Dark-chilling effects on carbohydrates metabolism

Table 4.3. Phosphoe*nol*pyruvate carboxylase (PEPC) and ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) activation state for control and one night-chilled plants of *Paspalum dilatatum*, *Cynodon dactylon* and *Zoysia japonica*. Carboxylating enzymes measurements were obtained from samples harvested inside the growth chamber at a PPFD of approximately 250-300 μmol m^{-2} s^{-1}. Data are mean ± SD of eight plants of each species *per* treatment. The statistical analysis was performed separately for each species. The different letters represent statistical differences at $P<0.05$.

	PEPC activation state (%)	Rubisco activation state (%)
P. dilatatum		
Control	22 ± 2.0 a	70 ± 6.6 a
1 Night Chilling	26 ± 1.0 b	60 ± 5.1 b
C. dactylon		
Control	48 ± 4.7 a'	45 ± 5.2 a'
1 Night Chilling	46 ± 4.6 a'	36 ± 2.7 b'
Z. japonica		
Control	62 ± 4.3 a''	38 ± 4.4 a''
1 Night Chilling	76 ± 3.8 b''	49 ± 6.1 b''

Soares, ASC (2008) PhD Thesis, FCUL, Portugal

Papers suggested to read:

Impacts of chilling temperatures on photosynthesis in warm-climate plants

Damian J. Allen and Donald R. Ort

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Journal of Experimental Botany, Vol. 62, No. 2, pp. 687–699, 2010
doi:10.1093/jxb/erq302 Advance Access publication 28 October, 2010
This paper is available online free of all access charges (see http://jxb.oxfordjournals.org/open_access.html for further details)

Journal of Experimental Botany
www.jxb.oxfordjournals.org

RESEARCH PAPER

Dorsoventral variations in dark chilling effects on photosynthesis and stomatal function in *Paspalum dilatatum* leaves

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Review

New Phytologist

Tansley review

Advances and challenges in uncovering cold tolerance regulatory mechanisms in plants

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Epigenetic Control of Plant Cold Responses

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Keywords: cold stress, DNA methylation, histone modifications, vernalization genes, cold acclimation, crosstalks